



2. Declaration or oath

☐ Enclosed

☐ original ☐ facsimile  
executed by:

☐ inventor(s)

☐ legal representative of inventor(s) 37 CFR 1.42 or 1.43

☐ joint inventor or person showing a proprietary interest  
on behalf of inventor who refused to sign or cannot be  
reached. 37 CFR 1.47.

☐ petition and statement required by 37 CFR 1.47  
also attached. See item 7 below for fee.

☒ Not Enclosed

☒ Application is made by a person authorized under 37 CFR  
1.41(c) on behalf of all of the above named inventor(s).  
The declaration or oath, along with the surcharge  
required by 37 CFR 1.16(e) can be filed subsequently.

☐ Showing that the filing is authorized. (Not required  
unless called into question. 37 CFR 1.41(d)).

NOTE: Where the filing is a completion in the U.S. of an international  
application under 35 U.S.C. 371(c)(4) then the declaration must  
be filed.

3. Assignment

☐ An assignment of the invention to \_\_\_\_\_  
\_\_\_\_\_

4. Certified Copy

☐ A certified copy of Patent Application(s)  
\_\_\_\_\_ from which priority is claimed.

NOTE: Must be referred to in oath or declaration. 37 CFR 1.55 and 163.

5. Fee Calculation

CLAIMS AS FILED			
Number Filed	Number Extra	Rate	Basic Fee \$ 760.00
Total Claims 20 -20=	0 x	\$ 18.00	0
Independent Claims 02 -03=	0 x	\$ 78.00	0
Multiple Dependent Claim(s), If Any	0 x	\$260.00	0

☐ Amendment cancelling extra claims enclosed

☐ Amendment deleting multiple dependencies enclosed

☐ Fee for extra claims is not being paid at this time

NOTE: If the fee for extra claims are not paid on filing they must be paid or the  
claims cancelled by amendment, prior to the expiration of the time period set  
for response by the Patent and Trademark Office in any notice of fee deficiency,  
37 CFR 1.16(d).

Filing Fee Calculation \$760.00

6. Small Entity Statement

☐ Verified statement that this is a filing by a small entity under 37 CFR 1.9 and 1.27.

Filing Fee Calculation (50% of above) \$\_\_\_\_\_

NOTE: If a verified statement is filed within 2 months of the date of payment of first fee then the excess fee paid will be refunded on request. Notice of January 20, 1983. 1027 TMOG 114.

7. Fee Payment Being Made At This Time

☒ Not Enclosed

☒ No filing fee is submitted. This and the surcharge required by 37 CFR 1.16(e) can be paid subsequently.

NOTE: Where the filing is a completion in the U.S. of an international application the fee must be paid.

☐ Enclosed

☐ filing fee \$\_\_\_\_\_

☐ recording assignment \$\_\_\_\_\_  
(\$40.00; 37 CFR 1.21(h)(i))

☐ petition fee for filing by other than all the inventors or person on behalf of the inventor where inventor refused to sign or cannot be reached. 37 CFR 1.47 and 1.17 (h) \$\_\_\_\_\_

Total fees enclosed \$\_\_\_\_\_

8. Method of Payment of Fees

☐ check in the amount of \$\_\_\_\_\_

☐ charge account No. \_\_\_\_\_ in the amount of \$\_\_\_\_\_  
A duplicate of this transmittal is attached.

NOTE: Fees should be itemized in such a manner that it is clear for which purpose the fees are paid. 37 CFR 1.22(b).

9. Authorization to Charge Additional fees

☐ The Commissioner is hereby authorized to charge the following additional fees which may be required to Account No. \_\_\_\_\_:

☐ 37 CFR 1.16 (filing fees and presentation of extra claims)

☐ 37 CFR 1.17 (application processing fees)

☐ 37 CFR 1.18 (issue fee at or before Mailing of Notice of Allowance, pursuant to 37 CFR 1.311(b))

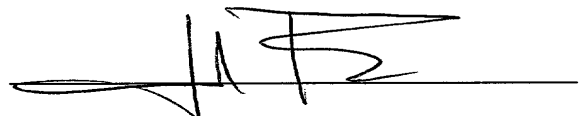
NOTE: 37 CFR 1.28(b) requires "Notification of any change in loss of entitlement to small entity status must be filed in the application ...prior to paying... issue fee".

10. Instructions As To Overpayment

☐ Credit Account No. \_\_\_\_\_ ☐ refund

c/o LADAS & PARRY  
5670 Wilshire Boulevard  
Suite 2100  
Los Angeles, CA 90036-5679

Telephone: (323) 934-2300  
Telefax: (323) 934-0202

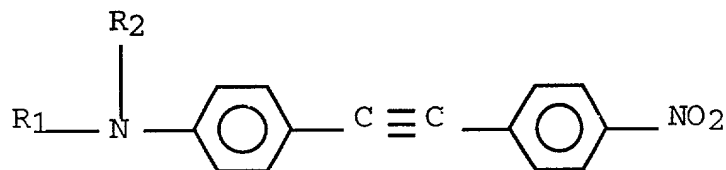
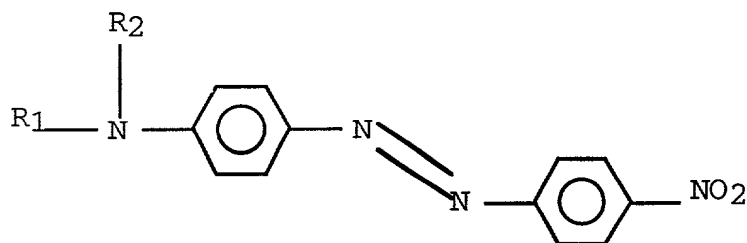
  
Attorney: John Palmer  
Reg. No.: 36,885

DOPANTS FOR LIQUID-CRYSTAL DEVICESBackground

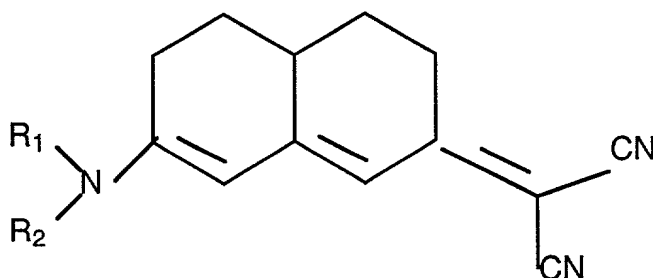
This invention concerns high-dielectric colorless or virtually colorless dopants for low-voltage and tunable clearing temperature liquid-crystal devices.

A few high dielectric anisotropy compounds have been reported in the literature.

For example, Wu et al., Asia Display, pp. 567-70 (1995) discloses nitro-amino azobenzenes and tolanses with the following structures:



In another example, Kippelen et al., Science 279, 54 (1998) discloses bicyano-amino polyene dyes with the following structure:



A general problem with the compounds and dyes disclosed by Wu et al. and Kippelen et al. is that their absorption is too large in the visible region. As a result, their light transmission is greatly reduced. This is particularly undesirable for some displays and electro-optic modulators where high transmittance is required.

### Summary

The invention involves new colorless or virtually colorless dopant compounds that exhibit an extraordinarily large dielectric anisotropy, a reduced elastic constant, and relatively low viscosity when mixed with liquid crystals. Therefore, adding a few percent of such dopant compounds to a liquid-crystal mixture reduces its operation voltage significantly. The low-voltage operation enables a low-cost electronic driver to be used. In addition, the clearing temperature and birefringence of the mixture can be tuned by

simply adjusting the concentration of the dopants.

### **Brief Description of the Drawings**

Figure 1 is a graph showing the voltage-dependent phase change of four E63™ LC cells that were studied.

Figure 2 is a graph showing the optical density of 1% the compound of formula I in a ZLI-2359™ LC mixture and the optical density of 1% the compound of formula IV in an ZLI-2359™ LC mixture.

Figure 3 is a graph showing dopant concentration-dependent clearing temperature (dots) and birefringence (squares) of an E7™ liquid-crystal mixture..

### **Description**

The dopant compounds of the present invention are colorless or virtually colorless. That is, their absorption in the visible region is very small. (Typically, the absorption loss in the visible region or spectrum at room temperature (e.g., approximately 20-30°C or approximately 22°C) is greater than or equal to 0 (or about .01%) and less than or equal to about 5%; preferably, the absorption loss in the visible region is greater than or equal to 0 (or about .01%) and less than or equal to about 1%; more preferably, the absorption loss in the visible region is greater than or equal to 0 (or about .01%) and less than or equal to about .05%; even more preferably, the absorption loss in the visible region is greater than or equal to 0 and less than or equal to about .01%; and ideally the absorption loss in the visible region is close to 0.) Absorption loss is defined as the

percentage of the input light that is absorbed by the medium.

The dopant compounds of the present invention also possess a very large dielectric anisotropy at room temperature of approximately 20-30°C or approximately 22°C (e.g., greater than about 50; preferably greater than about 60; and more preferably greater than about 70) and a low viscosity at room temperature of approximately 20-30°C or approximately 22°C (e.g., lower than about 50 centi-poise; preferably lower than about 30 centi-poise; and more preferably lower than about 15 centi-poise).

These dopant compounds help reduce the operation voltage for both polar and non-polar liquid-crystal (LC) mixtures. In addition, the nematic range and birefringence of LC mixtures can be tuned by adjusting the concentration of the dopant compounds of the present invention. That is, these dopant compounds can be used to tune the clearing temperature of LC mixtures.

Thus, the invention includes a composition comprising one or more of the dopant compounds and a liquid-crystal mixture. (A liquid-crystal mixture may comprise or consist of only one liquid-crystal compound or may comprise or consist of two or more liquid-crystal compounds, wherein a liquid-crystal compound is a compound that exhibits a liquid-crystal phase. Examples of liquid-crystal mixtures include, but are not necessarily limited to, Merck's E7<sup>TM</sup> liquid-crystal mixture, Merck's E63<sup>TM</sup> liquid-crystal mixture, and Merck's ZLI-2359<sup>TM</sup> liquid-crystal mixture. The reason for mixing two or more LC compounds to yield an LC mixture is to widen the LC mixture's temperature range (i.e., the range from the melting point to the clearing point) because a single LC compound may not have a wide enough temperature range. The usually preferred

storage temperature for an LC device is from about  $-40^{\circ}\text{C}$  to about  $80^{\circ}\text{C}$ . When two or more LC compounds are mixed in the proper concentration, the melting point of the resulting mixture may drop to the lowest available melting point.) The dopant compound or compounds may comprise any percentage of the composition. Thus, the dopant compound or compounds may comprise by weight about 99% or less of the composition; the dopant compound or compounds may comprise by weight about 75% or less of the composition; the dopant compound or compounds may comprise by weight about 50% or less of the composition; the dopant compound or compounds may comprise by weight about 25% or less of the composition; the dopant compound or compounds may comprise by weight about 15% or less of the composition; the dopant compound or compounds may comprise by weight about 10% or less of the composition; the dopant compound or compounds may comprise by weight about 5% or less of the composition; the dopant compound or compounds may comprise by weight about 3% or less of the composition; and the dopant compound or compounds may comprise by weight about 1% or less of the composition.

The composition described in the preceding paragraph preferably has at room temperature of approximately  $20-30^{\circ}\text{C}$  (or approximately  $22^{\circ}\text{C}$ ) a relatively high  $\partial n/\partial T$  (e.g., greater than about 0.005, or more preferably greater than about 0.01 or greater than about 0.05), wherein  $n$  is a refractive index of the composition at a visible wavelength (e.g., about  $4000\text{ \AA}$  to about  $7000\text{ \AA}$  or, more specifically, about  $633\text{ nm}$ ) and  $T$  is the temperature of the composition in  $^{\circ}\text{C}$ . The  $\partial n/\partial T$  represents the rate of refractive index change versus the temperature; and, thus, the unit measurement of  $\partial n/\partial T$  in  $^{\circ}\text{C}^{-1}$ . The larger the  $\partial n/\partial T$ , the lower the laser power needed for realizing the nonlinear refraction effect, which is desirable.

The invention includes a method for increasing a  $\partial n/\partial T$  of a liquid-



crystal mixture, the method comprising adding one or more of the dopant compounds to the liquid-crystal mixture to yield a resulting mixture. The invention also includes a method for reducing an operation voltage of a liquid-crystal mixture, the method comprising adding one or more of the dopant compounds to the liquid-crystal mixture to yield a resulting mixture. The invention includes a method for tuning a clearing temperature of a liquid-crystal mixture, the method comprising adding one or more of the dopant compounds to the liquid-crystal mixture to yield a resulting mixture. In addition, the invention includes a method for tuning birefringence of a liquid-crystal mixture, the method comprising adding one or more of the dopant compounds to the liquid-crystal mixture to yield a resulting mixture. The dopant compound or compounds may comprise any percentage of the resulting mixture. Thus, the dopant compound or compounds may comprise by weight about 99% or less of the resulting mixture; the dopant compound or compounds may comprise by weight about 75% or less of the resulting mixture; the dopant compound or compounds may comprise by weight about 50% or less of the resulting mixture; the dopant compound or compounds may comprise by weight about 25% or less of the resulting mixture; the dopant compound or compounds may comprise by weight about 15% or less of the resulting mixture; the dopant compound or compounds may comprise by weight about 10% or less of the resulting mixture; the dopant compound or compounds may comprise by weight about 5% or less of the resulting mixture; the dopant compound or compounds may comprise by weight about 3% or less of the resulting mixture; and the dopant compound or compounds may comprise by weight about 1% or less of the resulting mixture.

The low voltage operation of an LC device is highly desirable because it enables a low cost electronic driver to be used. Low threshold LC mixtures are particularly attractive for the cholesteric-LC display where the threshold voltage ( $V_{th}$ ) increases

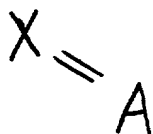
as the pitch length decreases. (D.L. White and G.N. Taylor, J. Appl. Phys. 45, 4718 (1974)) The recently developed polymer-stabilized cholesteric displays exhibit an excellent brightness and wide viewing angle. However, their operation voltage remain quite high ( $\sim 50 V_{rms}$ , wherein  $V_{rms}$  represents root-mean-square voltage). (D.K. Yang, et al., Appl. Phys. Lett. 64, 1905 (1994)) Consequently, there is an urgent need to reduce the operation voltage of these LC devices.

Based on the Freedericksz transition, the  $V_{th}$  of a homogeneously aligned LC cell is governed by the splay elastic constant ( $K_{11}$ ) and dielectric anisotropy ( $\Delta\epsilon$ ) of the LC material according to the formula:  $V_{th} = \pi(K_{11}/\Delta\epsilon)^{1/2}$ . A simple way to reduce  $V_{th}$  is to use high  $\Delta\epsilon$  LC's, i.e., polar LC's with a large dipole moment, such as cyano group. Several cyano-biphenyl LC's (e.g., 4-cyano-4'-n-pentylbiphenyl (5CB)) do exhibit a large dielectric anisotropy ( $\Delta\epsilon \sim 10$ ) and a relatively low melting point. These compounds have become the major components of many commercial LC mixtures, despite the fact that their clearing temperature ( $T_c$ ) is not sufficiently high. To enhance the clearing point of LC mixtures, some high- $T_c$  components are added. A general trend for the high- $T_c$  LC compounds is that their melting point is also very high. For example, the melting-point temperatures ( $T_{mp}$ ) of cyano-terphenyl (5CT) and cyano-diphenyl-diacetylene (PTTP-6CN) are 131°C and 145.3°C, respectively. A high melting point implies that the compound will have a poor solubility for forming eutectic mixtures.

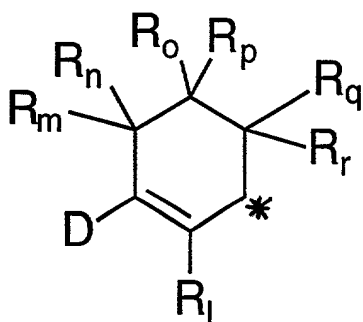
In this disclosure, we present some colorless (or virtually colorless), high-dielectric compounds for use as dopant materials for lowering the  $V_{th}$  of LC mixtures. Since these dopants possess a huge dielectric anisotropy, adding  $\sim 3\%$  of such a dopant to an LC

mixture is enough to significantly reduce  $V_{th}$  while keeping viscosity low.

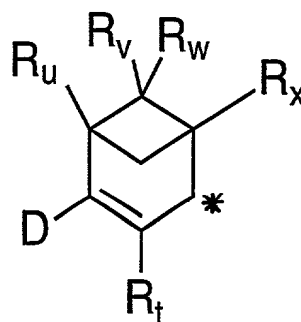
The invention comprises compounds illustrated below by the following formula A:



wherein X is selected from the group consisting of



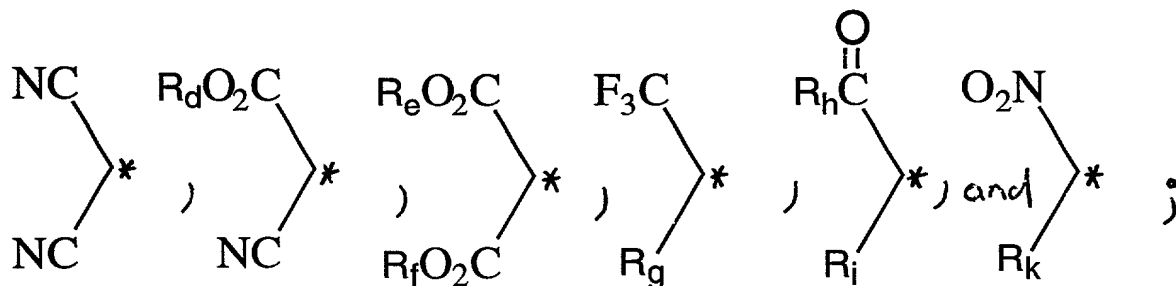
and



;

wherein D is selected from the group consisting of  $NR_aR_b$ ,  $OR_a$ ,  $SR_a$ ,  $PR_aR_b$ , and  $R_c$ ;

wherein A is selected from the group consisting of:

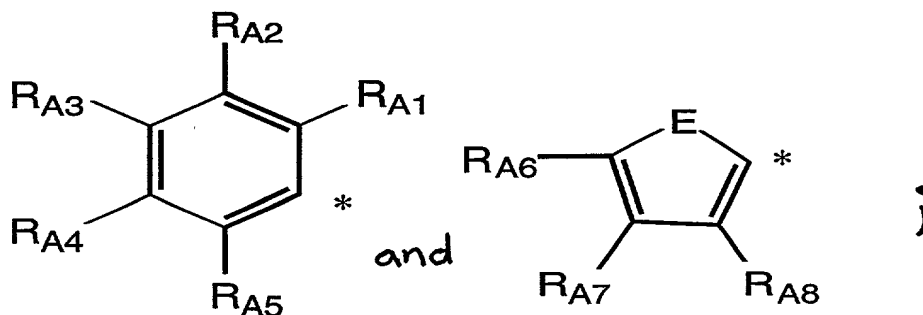


wherein  $R_a$ ,  $R_b$ , and  $R_c$  are the same or different and are each independently selected from the group consisting of: H; a linear, branched, or cyclic alkyl group;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta OR_{A1}$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta NR_{A2}R_{A3}$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta CN$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta Cl$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta Br$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta I$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta$ -Phenyl;  $-(CH_2)_\alpha(CF_2)_\gamma CF_3$ ; and an aryl group;

wherein  $R_d$ ,  $R_e$ ,  $R_f$ ,  $R_l$ ,  $R_m$ ,  $R_n$ ,  $R_o$ ,  $R_p$ ,  $R_q$ ,  $R_r$ ,  $R_s$ ,  $R_t$ ,  $R_u$ ,  $R_v$ ,  $R_w$ , and  $R_x$  are the same or different and are each independently selected from the group consisting of: H; a linear, branched, or cyclic hydrocarbon group that is saturated or unsaturated; a linear, branched, or cyclic alkyl group;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta OR_{A1}$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta NR_{A2}R_{A3}$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta CN$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta Cl$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta Br$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta I$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta$ -Phenyl;  $-(CH_2)_\alpha(CF_2)_\gamma CF_3$ ; and an aryl group;

wherein  $R_g$ ,  $R_h$ ,  $R_i$ , and  $R_k$  are the same or different and are each independently selected from the group consisting of: H; a linear, branched, or cyclic hydrocarbon group that is saturated or unsaturated; a linear, branched, or cyclic alkyl group;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta OR_{A1}$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta NR_{A2}R_{A3}$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta CN$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta Cl$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta Br$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta I$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta$ -Phenyl; an aryl group;  $-(CH_2)_\alpha(CF_2)_\gamma CF_3$ ;  $-CO_2R_d$ ; and  $-COR_d$ ;

wherein each aryl group is optionally independently selected from the group consisting of



wherein  $R_{A1}$ ,  $R_{A2}$ ,  $R_{A3}$ ,  $R_{A4}$ ,  $R_{A5}$ ,  $R_{A6}$ ,  $R_{A7}$ , and  $R_{A8}$  are the same or different and are each independently selected from the group consisting of H, a linear alkyl group, a branched alkyl group, and a cyclic alkyl group;

wherein E is selected from the group consisting of S, O, and  $NR_s$ ;

wherein the linear, branched, or cyclic hydrocarbon group that is saturated or unsaturated optionally includes up to 25 (or 8 or 5) carbon atoms (exemplary unsaturated hydrocarbons include, but are not necessarily limited to, ethylene, propylene, butene, methylpropene, pentene, hexene, methylbutene, ethyne, propyne, butyne, pentyne, hexyne, cyclopropene, cyclobutene, cyclopentene, cyclohexene, cycloheptene, cyclooctene, cyclononene, cyclobutadiene, and cyclohexadiene; exemplary saturated hydrocarbons are set forth in the next paragraph);

wherein the linear, branched, or cyclic alkyl group optionally includes up to 25 (or 8 or 5) carbon atoms (exemplary alkyl groups include, but are not necessarily limited to, methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, and nonyl, in the normal, secondary, iso, and neo attachment isomers; cyclopropane; cyclobutane; cyclopentane; cyclohexane; cycloheptane; cyclooctane; cyclononane; and decalin);

wherein  $\alpha$  is an integer that is greater than or equal to 0 and less than or equal to 25 (or less than or equal to 8 or 5 or 2 or 1);

wherein  $\beta$  is an integer that is greater than or equal to 0 and less than or equal to 25 (or less than or equal to 8 or 5 or 2 or 1);

wherein  $\gamma$  is an integer that is greater than or equal to 0 and less than or equal to 25 (or less than or equal to 8 or 5 or 2 or 1);

wherein when D is  $\text{NR}_a\text{R}_b$ , then  $\alpha$  optionally is greater than or equal to 1 and less than or equal to 25;

wherein when  $\text{R}_1$ ,  $\text{R}_m$ ,  $\text{R}_n$ ,  $\text{R}_q$ , and  $\text{R}_r$  are each H, and  $\text{R}_o$ ,  $\text{R}_p$ , and D are each  $-\text{CH}_3$ , A optionally is not  $\text{C}(\text{CN})(\text{CN})$ ;

wherein when  $\text{R}_1$ ,  $\text{R}_m$ ,  $\text{R}_n$ ,  $\text{R}_o$ , and  $\text{R}_p$  are each H, and  $\text{R}_q$ ,  $\text{R}_r$ , and D are each  $-\text{CH}_3$ , A optionally is not  $\text{C}(\text{CN})(\text{CN})$ ;

wherein when  $\text{R}_1$ ,  $\text{R}_o$ ,  $\text{R}_p$ ,  $\text{R}_q$ , and  $\text{R}_r$  are each H, and  $\text{R}_n$ ,  $\text{R}_m$ , and D are each  $-\text{CH}_3$ , A optionally is not  $\text{C}(\text{CN})(\text{CN})$ ;

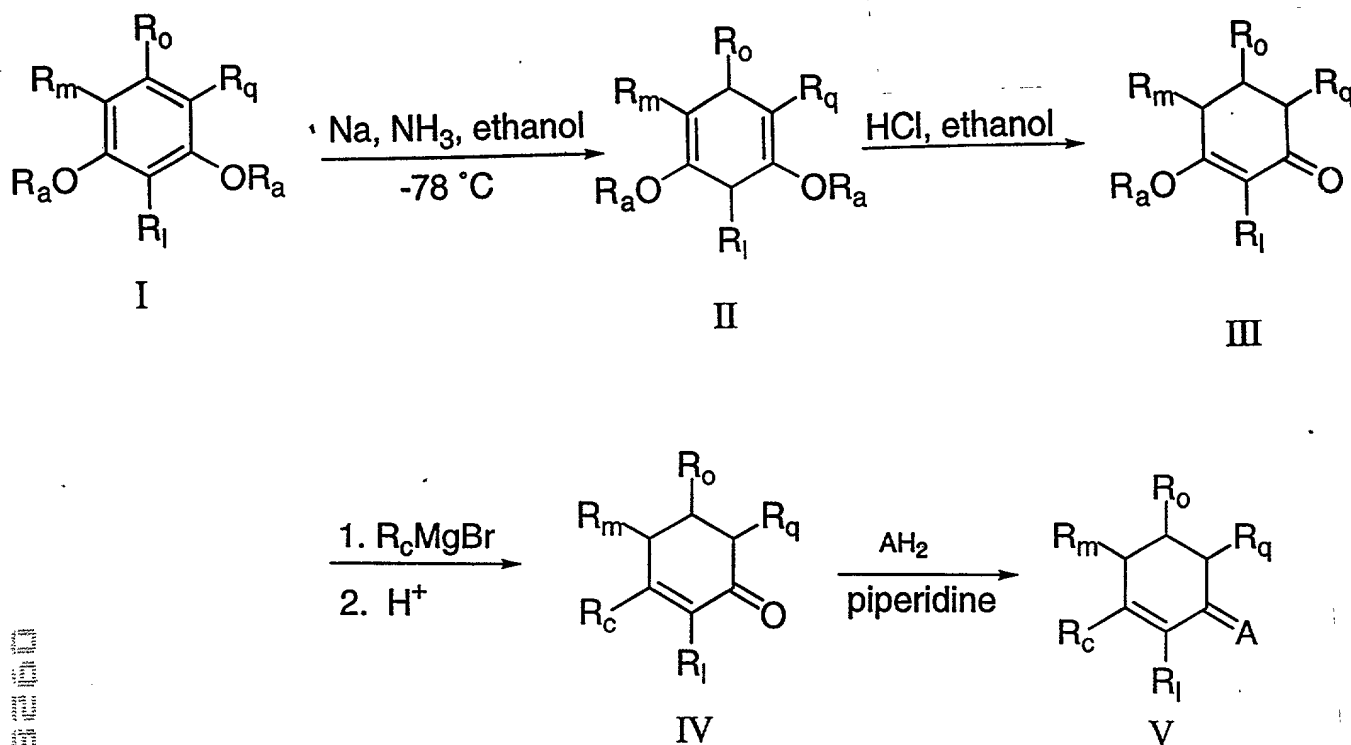
wherein when  $\text{R}_1$ ,  $\text{R}_m$ ,  $\text{R}_n$ ,  $\text{R}_o$ ,  $\text{R}_p$ ,  $\text{R}_q$ , and  $\text{R}_r$  are each H, and D is  $-\text{CH}_3$ , A optionally is not  $\text{C}(\text{CN})(\text{CN})$ ; and

wherein \* represents an attachment point (e.g., the attachment point at which A attaches to X).

In one embodiment, preferably in formula A,  $\text{R}_1$ ,  $\text{R}_m$ ,  $\text{R}_n$ ,  $\text{R}_o$ ,  $\text{R}_p$ ,  $\text{R}_q$ ,  $\text{R}_r$ ,  $\text{R}_t$ ,  $\text{R}_u$ ,  $\text{R}_v$ ,  $\text{R}_w$ , and  $\text{R}_x$  are each H, A is  $\text{C}(\text{CN})(\text{CN})$ , and D is  $\text{R}_y$  or  $\text{OR}_y$ , wherein  $\text{R}_y$  is selected from the group consisting of a linear alkyl group, a branched alkyl group, and an aryl group.

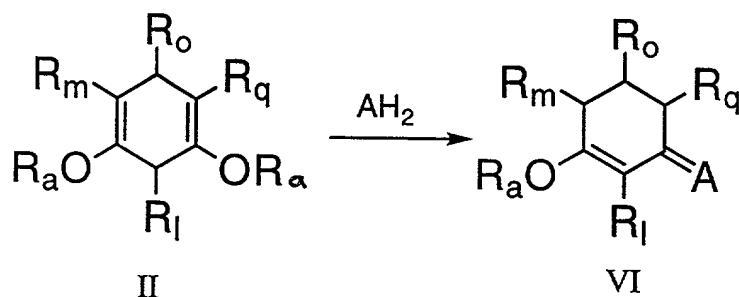
The procedures for making the above-described compounds are set forth below schematically.

Procedure 1:

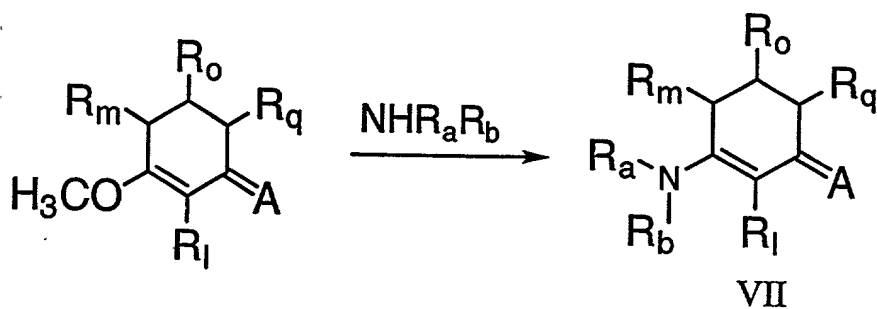


The first step in procedure 1 (i.e., the step that uses compound I to make compound II) is called a Birch reduction. The Birch reduction is described in greater detail in the following two articles, which are incorporated herein by this reference: E. Piers, J.R. Grierson, *J. Org. Chem.*, 1997, 42, 3755-3757; and P. Radlick, *J. Org. Chem.*, 1965, 30, 3209-3211. The last step in procedure 1 (i.e., the step that uses compound IV to make compound V) and below-described procedures 3a, 3b, 3c, and 3d are called Knoevenagel condensation reactions. Knoevenagel condensation reactions are described in greater detail in the following two articles, which are incorporated herein by this reference: R. Lemke, *Synthesis*, 1974, 359-361; and A.J. Fatiadi, *Synthesis*, 1978, 165-204.

Procedure 2a:

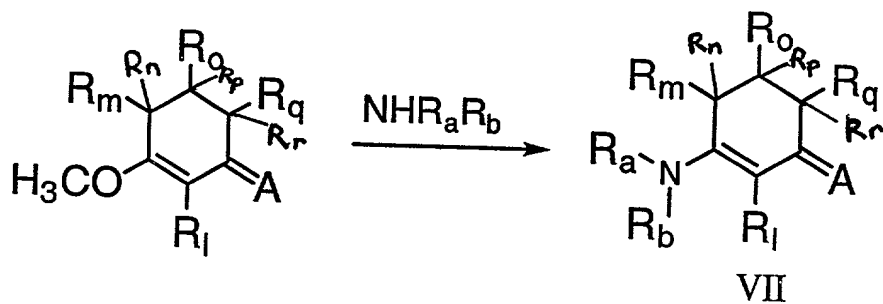


Procedure 2b:



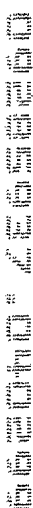
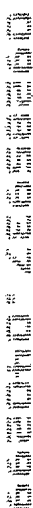
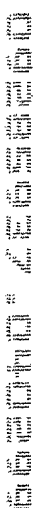
In procedure 2b, R<sub>a</sub> and R<sub>b</sub> are not both aryl groups.

Procedure 2c:

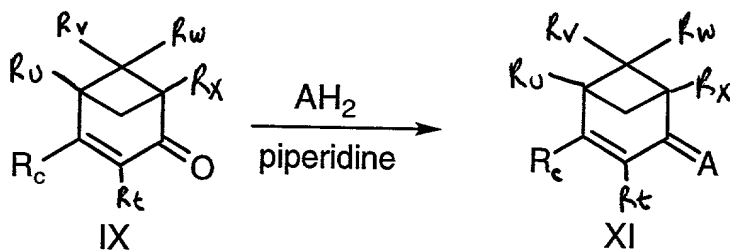


In procedure 2c, R<sub>a</sub> and R<sub>b</sub> are not both aryl groups.

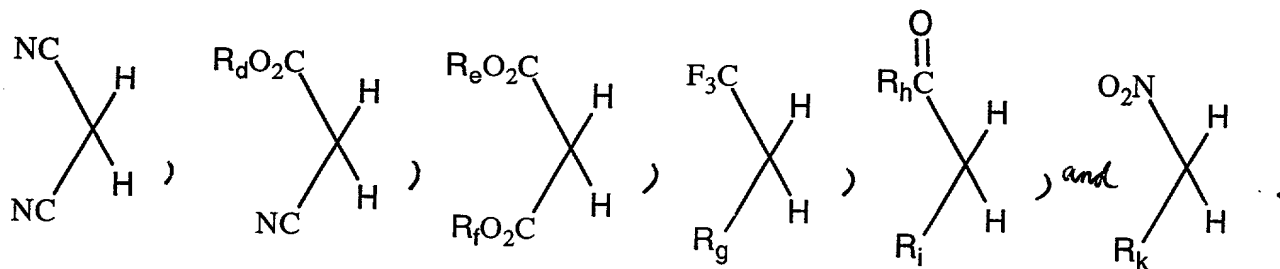


[illegible][illegible][illegible]

Procedure 3d:

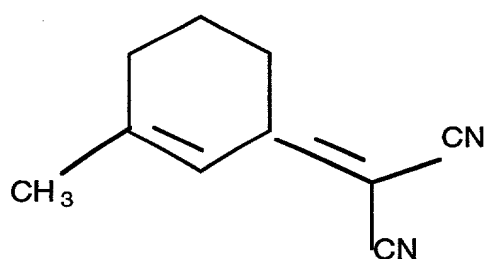


In the procedures described above,  $\text{AH}_2$  is selected from the group consisting of:

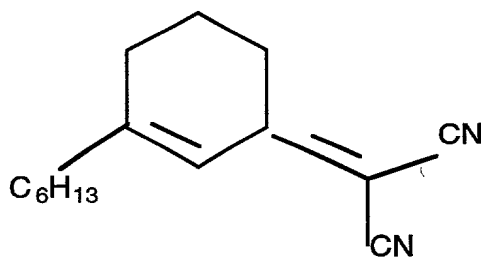


Compounds wherein D is  $SR_a$  may be made by a procedure analogous to procedure 2a above; and compounds wherein D is  $PR_aR_b$  may be made by a procedure analogous to procedure 2b above.

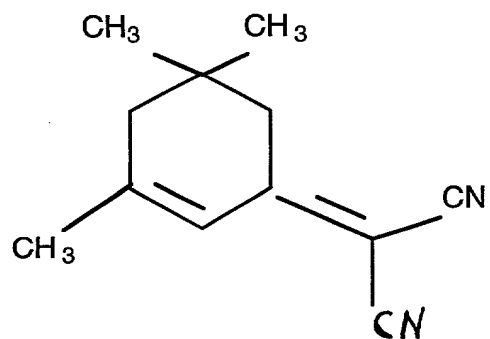
Four compounds of the above-described invention were studied. Their molecular structures are shown below in formulas I-IV.



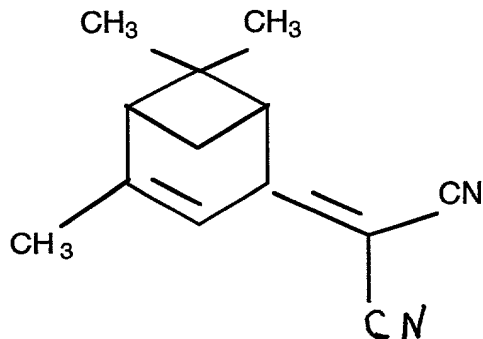
(I)



(II)



(III)



(IV)

The melting point (in °C) and heat fusion enthalpy (in kcal/mol) of compounds I-IV are set forth below in Table 1.

Table 1

Compound	Melting Point (in °C)	Heat Fusion Enthalpy (in kcal/mol)
Formula I	84.0	5.93
Formula II	3.4	5.32
Formula III	74.9	6.35
Formula IV	61.2	4.98

There are several reasons for designing these linear polyene molecules. First, these linear polyene molecules exhibit a considerable charge transfer that is confined along the quasi-one-dimensional  $\pi$ -conjugated bridge (i.e., along the bridge comprising two or more unsaturated (e.g., double) bonds). Second, the incorporation of the polyene into a ring-containing bridge prevents isomerization resulting in improved thermal and photochemical stability. Third, the ability to change alkyl groups allows one to control the melting temperature so as to tune the solubility to the LC's. Fourth, the two cyano or cyano/amino groups provide (or more broadly the A group in formula A provides) a huge push-pull effect for enhancing the dipole moment; and fifth, the cyano acceptors themselves have (or more broadly the A group in formula A has) a large group dipole moment.

The threshold voltage, visco-elastic coefficient, and absorption spectra of the compounds of formulas I-III were measured. (The compound of formula IV is a chiral material, so its physical

properties were not studied.) In the sample preparation, we mixed 3% of each compound in a commercial E63™ LC mixture. (E63™ LC mixture is a Merck mixture. Its major components are alkyl cyano-biphenyl and alkoxy cyano-biphenyl. This mixture was used because it has very wide nematic range: its melting point is below -40°C and its clearing point is about 87°C.) These guest-host mixtures were then injected into a homogeneous-aligned cell. The cell gap (i.e., the gap between substrates in a liquid-crystal display) was controlled by spacers to be about 5.6 μm, and the pretilt angle was ~2°. (The pretilt angle is the angle inclined on the liquid crystal substrates. This way, liquid crystals know which way to relax back without creating instability. A typical pretilt angle of an LC cell is 1-5°.) The voltage-dependent phase change method was used for determining the threshold voltage. (The voltage-dependent phase change method has been described in Wu, et al., Phys. Rev. A, 42, 2219-2227 (1990), which is incorporated herein by this reference.) Results measured at λ=633 nm are plotted in Figure 1.

In Figure 1, the axis labelled "Phase Change (π)" is the phase of a liquid crystal cell, wherein the phase is described as  $\delta = 2\pi d \Delta n / \lambda$ ; where d is the cell gap, Δn is the effective birefringence and λ is the wavelength. When a voltage is applied to the liquid crystal cell, the effective birefringence is decreased as the applied voltage is increased. Thus, a phase change 0.5π means  $\delta(V=0) - \delta(V) = 2\pi d [\Delta n(V=0) - \Delta n(V)] / \lambda = 0.5\pi$ .

In Figure 1, the solid circles represent experimental data of pure E63™ LC mixture; the open circles are for 3% of the compound of formula I dissolved in E63™ LC mixture (i.e., 3% by weight of the total mixture of the compound of formula I and the E63™ LC mixture); the diamonds are for 3% of the compound of formula II dissolved in E63™ LC mixture (i.e., 3% by weight of the total mixture of the compound of formula II and the E63™ LC mixture);

and the triangles are for 3% of the compound of formula III dissolved in E63™ LC mixture (i.e., 3% by weight of the total mixture of the compound of formula III and the E63™ LC mixture).

Results for the compounds of formulas I, II, and III overlap closely due to their similar structures. In the vicinity of threshold voltage, the voltage-dependent phase change is linear. From this linear extrapolation, the threshold voltage is obtained. From Figure 1, the  $V_{th}$  of E63™ LC mixture at  $f=2$  KHz ( $f = 2$  KHz means the frequency of the applied AC voltage) and room temperature (approximately 22°C) is found to be  $\sim 1.01 V_{rms}$ . Adding 3% by weight of the compounds of formulas I, II and III lowers the threshold voltage to  $0.93 V_{rms}$ . Knowing that E63™ LC mixture's  $\Delta\epsilon$  is 14.6, we estimate that the  $\Delta\epsilon$  of the compounds of formulas I, II, and III is extrapolated to be about 50. The observed dielectric anisotropy in the compounds of the present invention is similar to the dielectric anisotropy of the nitro-amino azobenzenes and tolans described in S.T. Wu, et al., Appl. Phys. Lett. 64, 2191 (1994) and Asia Display pp. 567 (1995), and is smaller than the dielectric anisotropy of the bicyano-amino polyenes described in Wu, et al., Jpn. J. Appl. Phys. 37, L1254-56 (1998). However, these previously reported compounds are colored. They have strong absorption in the visible region; and, thus, use of these previously reported compounds is limited.

Increasing dopant concentration would further reduce threshold voltage at the price of increased mixture viscosity. To evaluate the viscosity of these compounds, the decay time was measured for these LC cells with 3% concentrations (by weight) of the compounds

of formulas I, II, and III. Through time-dependent phase change measurements, the visco-elastic coefficients ( $\gamma_1/K_{11}$ ) of the guest-host mixtures were determined. (The time-dependent phase change method has been described in Wu, et al., Phys. Rev. A, 42, 2219-2227 (1990).) The measured visco-elastic coefficient ( $\gamma_1/K_{11}$ ) for 3% of the compound of formula I dissolved in E63<sup>TM</sup> LC mixture was 20 ms/ $\mu\text{m}^2$ ; the measured visco-elastic coefficient ( $\gamma_1/K_{11}$ ) for 3% of the compound of formula II dissolved in E63<sup>TM</sup> LC mixture was 23.8 ms/ $\mu\text{m}^2$ ; and the measured visco-elastic coefficient ( $\gamma_1/K_{11}$ ) for 3% of the compound of formula III dissolved in E63<sup>TM</sup> LC mixture was 23.7 ms/ $\mu\text{m}^2$ .

The viscosity of an LC compound is determined by its moment of inertia, molecular shape, and temperature. The compound of formula I has the lowest viscosity as expected from theory because it has the shortest or smallest side chain (i.e., the shortest or smallest D group). (Wu, et al., Jpn. J. Appl. Phys. 37, L1254-56 (1998).) According to this theory, the smaller X group is in formula A, the lower the viscosity and the higher the melting point and the clearing temperature.

The absorption spectra of the compounds of formulas I, II, and III are nearly identical because of the structural similarity of these compounds. To measure absorption, 1% of the compound of formula I (by weight) was dissolved in a UV transparent LC host, ZLI-2359<sup>TM</sup> LC mixture; and 1% of the compound of formula IV (by weight) was dissolved in another ZLI-2359<sup>TM</sup> LC mixture. (ZLI-2359<sup>TM</sup> LC mixture, which is a UV transparent liquid crystal mixture made by Merck, includes some cyclohexane compounds that don't absorb UV light. Thus, ZLI-2359<sup>TM</sup> LC mixture is a good host for UV absorption measurements.) A homogeneous cell with an approximately 6- $\mu\text{m}$  cell gap was used for measurements. The results are shown in Figure 2, wherein "a.u." represents arbitrary units. Figure 2 shows that

the compounds of formula I and IV are highly transparent throughout the entire visible spectral region.

The clearing temperature ( $T_c$ ) of such a guest-host system is reduced much faster than the linear extrapolation from a eutectic mixture:  $(T_c)_{gh} = x(T_c)_g + (1-x)(T_c)_h$ , wherein  $x$  is the concentration of the dopant/guest, "g" refers to the guest, and "h" refers to the host. The host mixture E63™ LC mixture's clearing-point temperature is ~87°C. When 3% of the compound of formula II is added to the host, the extrapolated clearing-point temperature ( $T_c$ ) should be ~84.5°C, according to the formula set forth in the first sentence of this paragraph. However, the measured  $T_c$  was ~65°C. This indicates that the compound of formula II causes a larger-than-expected molecular separation. This is evidenced by the fact that the mixture birefringence drops from 0.22 for pure E63™ LC mixture to 0.21 and  $K_{11}$  drops from 12.6 to 11.2 pico-Newton after 3% of the compound of formula II is added to the E63™ LC mixture.

A high clearing point (e.g., about 70-100°C) is normally preferred, but in some circumstances, a low clearing point finds interesting applications as well. For example, for nonlinear optical effects using isotropic LC's, it is important to have an LC mixture with an isotropic phase (i.e., a phase with no visible crystals) below room temperature. (The isotropic phase is the phase at which the liquid-crystalline behaviors disappear. As the temperature goes beyond the clearing temperature, the liquid crystal becomes an isotropic liquid. That means many or all the anisotropic behaviors, such as optical and dielectric anisotropy, disappear.) The light scattering of an LC at the isotropic state is 2-3 orders of magnitude lower than that in the nematic state. (S.T. Wu and K.C. Lim, Appl. Opt. 26, 1722-1727 (1987).) (The nematic state means the temperature range in which the nematic phase exists.



Liquid crystal exists in only a certain temperature range. The sequence of phase transition is: crystalline phase, nematic phase, and isotropic phase.)

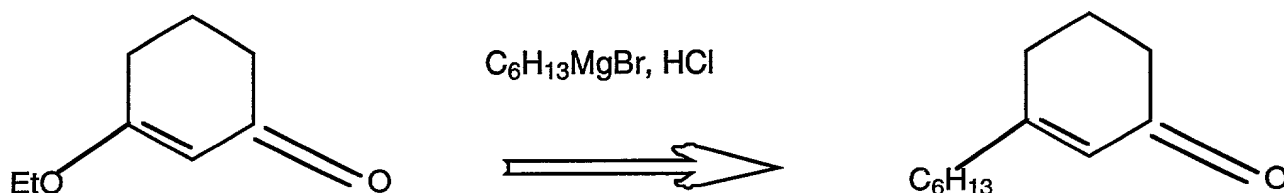
Another potential application of this tunable  $T_c$  is to control the mixture with large temperature-dependent refractive indices,  $\partial n/\partial T$ . It is well-known that  $\partial n/\partial T$  is much enhanced when the temperature is about 2-3 degrees Centigrade below  $T_c$ . (I.C. Khoo and S.T. Wu, Optics and Nonlinear Optics of Liquid Crystals (World Scientific, Singapore, 1993)) For example, to operate a liquid crystal device at room temperature (e.g., 22°C), then one must design a liquid-crystal mixture with a clearing point about 2-5 degrees Centigrade above room temperature in order to take advantage of a large  $\partial n/\partial T$ .

Figure 3 shows the concentration-dependent clearing temperature (left) and birefringence (right) of a Merck E7™ liquid-crystal mixture. The compound of formula II was used as the guest dopant; and an E7™ LC mixture was used as the host. The major component of an E7™ LC mixture is cyano-biphenyl. The melting point of the E7™ LC mixture is about 59.5°C; and  $\Delta n$  is about 0.224 at room temperature (about 22°C) and  $\lambda=633\text{nm}$ . As the guest concentration increased, both the clearing point and birefringence decreased almost linearly. At about 10% concentration by weight (i.e., when the guest comprised about 10% by weight of the guest-host mixture), the guest-host mixture's clearing point dropped to about 28°C; and birefringence dropped to about 0.135. The decreased birefringence is partly related to the decreased clearing point. At a low clearing point, the corresponding order parameter of the mixture at room temperature is reduced. On the other hand, at 10% concentration, the guest-host mixture's melting temperature was suppressed to about -30°C. Thus, the 10% guest-host mixture not only had a large  $\partial n/\partial T$  (the rate of refractive index change) at room temperature (about 22°C), but also had a low melting

temperature for practical applications.

The compounds of formulas I, II, III, and IV were made by a Knoevenagel reaction between ketones and malononitrile with a few drops of piperidine. Details regarding procedures 1, 2a, 2b, 2c, 3a, 3b, 3c, and 3d, which are described above, can be found in the following preparation procedures.

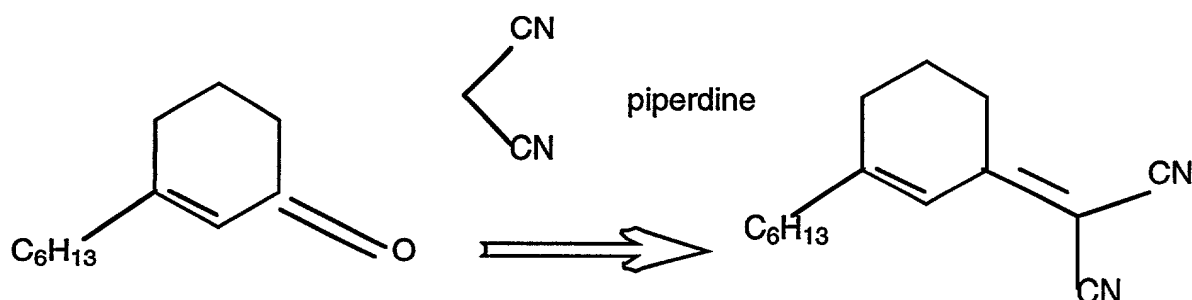
Preliminary step: Preparing 3-Hexyl-2-cyclohexenone



To a solution of 3-ethoxy-2-cyclohexenone (8.62 g, 61.50 mmol) in dry THF (tetrahydrofuran), hexylmagnesium bromide (15.38 mL, 2.0 M, 30.75 mmol) was added dropwise with stirring. The mixture was kept at 0°C (in an ice-water bath) during the whole process and then was allowed to warm (the ice-water bath was removed) to ambient temperature (approximately 22°C). Hydrochloric acid (10 mL, 3.0 M) was added to the above mixture. The mixture was extracted with diethylether 3 times. The combined organic layers were washed with water and then dried over magnesium sulfate. The product was further purified by flash chromatography on silica gel using 10:100 (dichloromethane:hexane (volume:volume)) to yield 6.17 g (xx%) of 3-hexyl-2-cyclohexenone.  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  5.78 (s, 1 H), 2.40-2.20 (m, 4 H), 2.20-2.10 (t,  $J$  = 7.37 Hz, 2H), 1.90 (p,  $J$  = 6.50 Hz, 2 H), 1.42 (t,  $J$  = 7.30 Hz, 2 H), 1.22 (br, 6 H), 0.81 (t,  $J$  = 6.70 Hz, 3 H).  $^{13}\text{C}$  NMR (75 MHz,

CDCl<sub>3</sub>): 200.06, 167.00, 126.04, 38.49, 37.80, 32.02, 30.11, 29.35, 27.35, 23.21, 22.95, 14.42, GC/MS calculated for C<sub>12</sub>H<sub>20</sub>O 180.15, found 180.15. The foregoing gas chromatography/mass spectrometry measurements confirmed the structure.

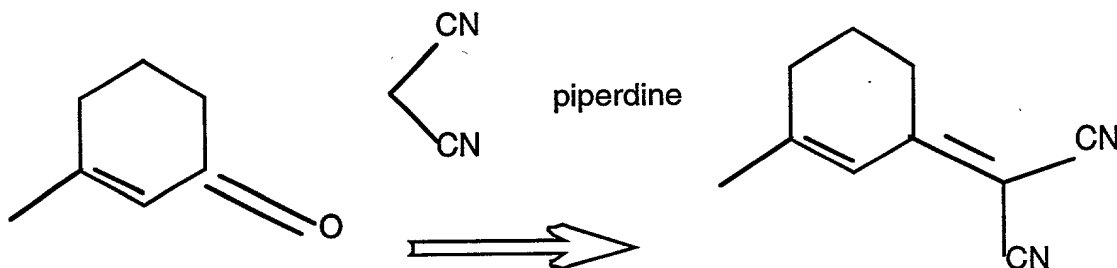
Preparing the compound of formula II



3-Hexyl-2-cyclohexenone (6.17 g, 34.22 mmol) and malononitrile (6.78 g, 102.63 mmol) and piperidine (2 drops (i.e. approximately 0.2 ml)) were stirred overnight (approximately 12 hours). The mixture was purified by flash chromatography on silica gel using 10:100 (dichloromethane:hexane (volume:volume)) to yield the compound of formula II (6.62 g (85%)). <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>): δ 6.57 (s, 1 H), 2.71 (t, J = 6.31 Hz, 2 H), 2.31 (m, 4 H), 1.86 (p, J = 6.12 Hz, 2 H), 1.51 (t, J = 7.31 Hz, 2 H), 1.29 (br, 6 H), 0.88 (t, J = 6.60 Hz, 3 H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>): 171.32, 167.03, 121.27, 121.08, 113.71, 112.97, 39.60, 32.03, 30.43, 29.87, 29.49, 27.83, 23.00, 22.11, 14.51. HRMS (high resolution mass spectrometry) calculated for C<sub>15</sub>H<sub>20</sub>N<sub>2</sub> 228.1626, found 228.1617. Elemental analysis calculated for C<sub>15</sub>H<sub>20</sub>N<sub>2</sub>; C, 78.90; H, 8.82; N,

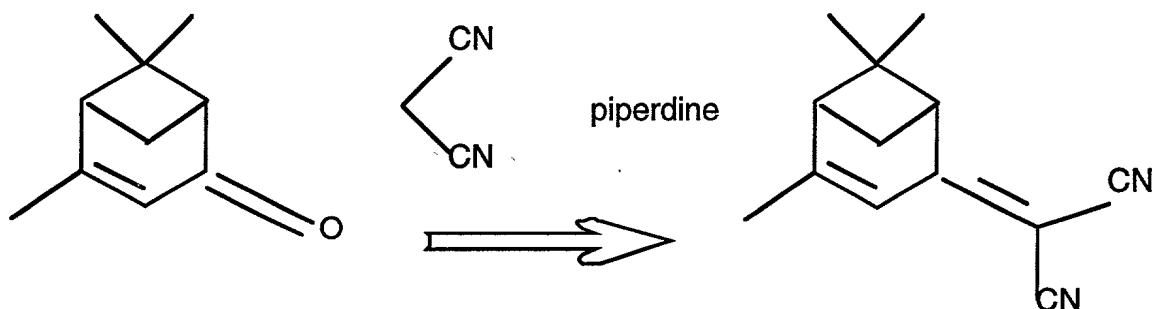
12.26. Found: C, 78.94; H, 8.87; N, 12.20. UV-Vis in  $\text{CH}_2\text{Cl}_2$   
 $\lambda_{\text{max}} = 305 \text{ nm}$ . The foregoing data confirm the final product.

Preparing the compound of formula I



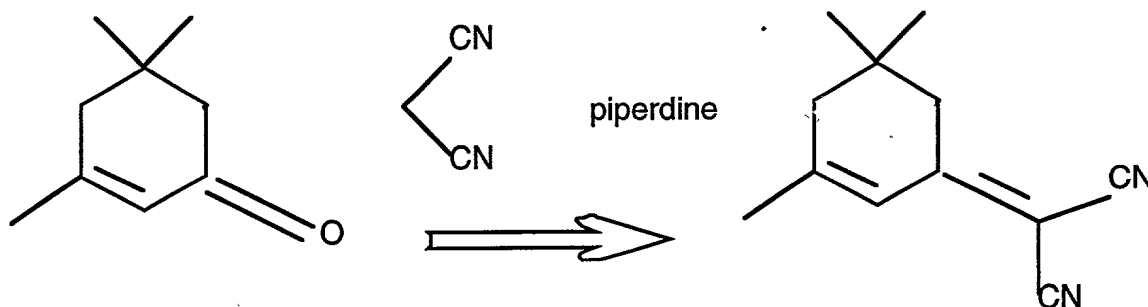
3-Methyl-2-cyclohexen-1-one (2.0 g, 18.16 mmol), malononitrile (3.60 g, 54.47 mmol) and piperidine (3 drops (i.e., approximately 0.2 or 0.3 ml) were heated to 80°C overnight (approximately 12 hours). The product was purified by flash chromatography with hexane:acetone (10:1 (volume:volume)) on silica gel to give 1.78 g (62%) of the compound of formula I. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>): δ 6.63 (s, 1 H), 2.71 (t, J = 6.50 Hz, 2 H), 2.35 (t, J = 5.78 Hz, 2 H), 2.08 (s, 3 H), 1.90 (p, J = 6.34 Hz, 2 H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>): 171.20, 162.47, 122.18, 121.08, 113.68, 112.92, 31.85, 29.57, 25.84, 21.96. Anal. calculated for C<sub>10</sub>H<sub>10</sub>N<sub>2</sub>; C, 75.92; H, 6.37; N, 17.70. Found: C, 75.80; H, 6.42; N, 17.85. UV-Vis in  $\text{CH}_2\text{Cl}_2$   $\lambda_{\text{max}} = 305 \text{ nm}$ . The foregoing data for NMR, elemental analysis, and the compound's UV-Vis spectrometry confirm the structural identity of the final product.

Preparing the compound of formula IV



(1S)-(-)-Verbenone (7.89 g, 52.50 mmol), malononitrile (10.05 g, 157.50 mmol), and piperidine (0.29 mL) were heated to 80°C overnight (approximately 12 hours). The product was purified by flash chromatography with hexane:acetone (10:1) on silica gel to give 7.49 g (72%) of the compound of formula IV.  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  6.48 (s, 1 H), 3.33 (t,  $J$  = 5.55 Hz, 1 H), 2.83 (q,  $J$  = 5.40 Hz, 1 H), 2.49 (t,  $J$  = 5.53 Hz, 1 H), 2.10 (s, 3 H), 1.92 (d,  $J$  = 9.29 Hz, 1 H), 1.57 (s, 3 H), 0.93 (s, 3 H). HRMS calcd for  $\text{C}_{13}\text{H}_{15}\text{N}_2$  199.1235, found 199.1232. Anal. calculated for  $\text{C}_{13}\text{H}_{15}\text{N}_2$ ; C, 78.75; H, 7.11; N, 14.12. Found: C, 78.79; H, 7.09; N, 14.15. UV-Vis in  $\text{CH}_2\text{Cl}_2$   $\lambda_{\text{max}}$  = 320 nm. The foregoing data for NMR, elemental analysis, and the compound's UV-Vis spectrometry confirm the structural identity of the final product.

Preparing the compound of formula III



The compound of formula III was synthesized in the same manner as described above for the compound of formula I. Isophorone (7.25 g, 52.46 mmol), malononitrile (10.05 g, 157.50 mmol), piperidine (0.29 mL) were heated to 80°C overnight (approximately 12 hours). The product was purified by flash chromatography with hexane:acetone (10:1) on silica gel to give 6.89 g (73%) of the compound of formula III. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>): δ 6.63 (s, 1 H), 2.53 (s, 2 H), 2.20 (s, 2 H), 2.05 (s, 3 H), 1.03 (s, 6 H). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>): 170.88, 160.37, 121.07, 113.70, 112.92, 46.21, 43.18, 32.88, 28.33, 25.79. HRMS calculated for C<sub>12</sub>H<sub>14</sub>N<sub>2</sub> 185.1157, found 186.1150. Anal. calculated for C<sub>12</sub>H<sub>14</sub>N<sub>2</sub>: C, 77.38; H, 7.57; N, 15.03. Found: C, 77.35; H, 7.59; N, 15.04. UV-Vis in CH<sub>2</sub>Cl<sub>2</sub> λ<sub>max</sub> = 304 nm. The foregoing data for NMR, elemental analysis, and the compound's UV-Vis spectrometry confirm the structural identity of the final product.

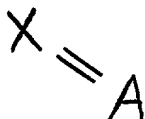
All of the measurements set forth in this application are approximations.

The invention illustratively disclosed herein suitably may be practiced in the absence of any element which is not specifically disclosed herein.

The following claims are entitled to the broadest possible scope consistent with this application. The claims shall not necessarily be limited to the preferred embodiments or to the embodiments shown in the examples.

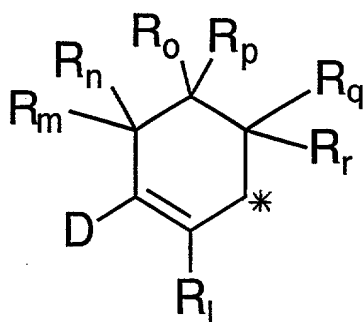
## Claims

1. A compound having a formula A:

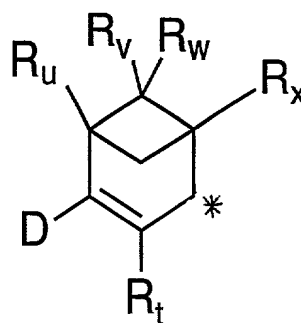


(formula A)

wherein X is selected from the group consisting of



and

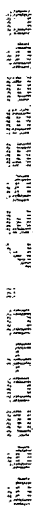


;

wherein D is selected from the group consisting of NR<sub>a</sub>R<sub>b</sub>, OR<sub>a</sub>, SR<sub>a</sub>, PR<sub>a</sub>R<sub>b</sub>, and R<sub>c</sub>;

wherein A is selected from the group consisting of:

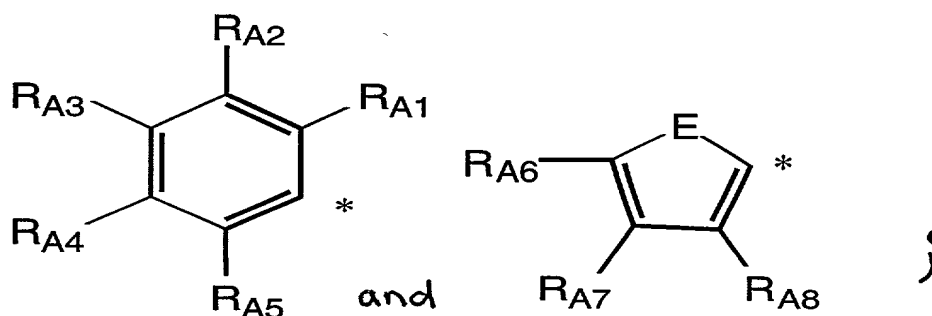




wherein  $R_d$ ,  $R_e$ ,  $R_f$ ,  $R_l$ ,  $R_m$ ,  $R_n$ ,  $R_o$ ,  $R_p$ ,  $R_q$ ,  $R_r$ ,  $R_s$ ,  $R_t$ ,  $R_u$ ,  $R_v$ ,  $R_w$ , and  $R_x$  are the same or different and are each independently selected from the group consisting of: H; a linear, branched, or cyclic hydrocarbon group that is saturated or unsaturated; a linear, branched, or cyclic alkyl group;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta OR_{A1}$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta NR_{A2}R_{A3}$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta CN$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta Cl$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta Br$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta I$ ;  $-(CH_2CH_2O)_\alpha-(CH_2)_\beta$ -Phenyl;  $-(CH_2)_\alpha(CF_2)_\gamma CF_3$ ; and an aryl group;

30

wherein each aryl group is optionally independently selected from the group consisting of



wherein  $R_{A1}$ ,  $R_{A2}$ ,  $R_{A3}$ ,  $R_{A4}$ ,  $R_{A5}$ ,  $R_{A6}$ ,  $R_{A7}$ , and  $R_{A8}$  are the same or different and are each independently selected from the group consisting of H, a linear alkyl group, a branched alkyl group, and a cyclic alkyl group;

wherein E is selected from the group consisting of S, O, and  $NR_s$ ;

wherein the alkyl group is optionally substituted or unsubstituted and optionally includes up to 25 carbon atoms;

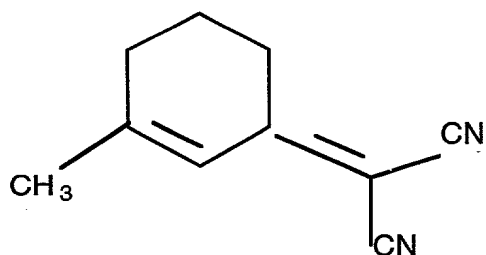
wherein  $\alpha$  is an integer that is greater than or equal to 0 and less than or equal to 25;

wherein  $\beta$  is an integer that is greater than or equal to 0 and less than or equal to 25; and

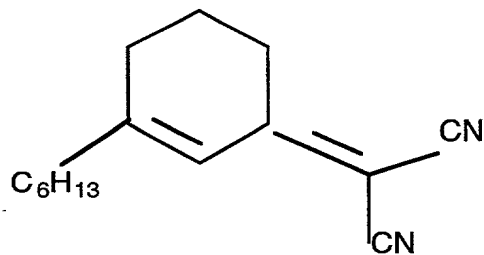
wherein  $\gamma$  is an integer that is greater than or equal to 0 and less than or equal to 25.

2. A compound as claimed in Claim 1, wherein  $R_1$ ,  $R_m$ ,  $R_n$ ,  $R_o$ ,  $R_p$ ,  $R_q$ ,  $R_r$ ,  $R_t$ ,  $R_u$ ,  $R_v$ ,  $R_w$ , and  $R_x$  are each H; wherein A is  $C(CN)(CN)$ ; and wherein D is  $R_y$  or  $OR_y$ , wherein  $R_y$  is selected from the group consisting of the linear alkyl group, the branched alkyl group, the cyclic alkyl group, and the aryl group.

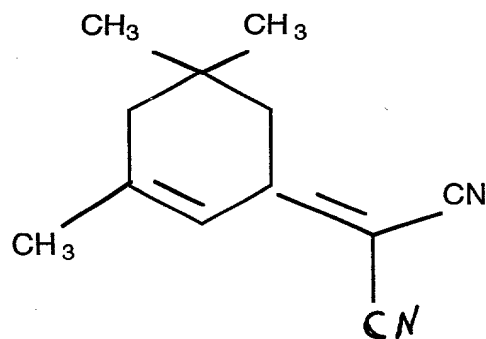
3. A compound as claimed in Claim 1, wherein the compound is selected from the group consisting of



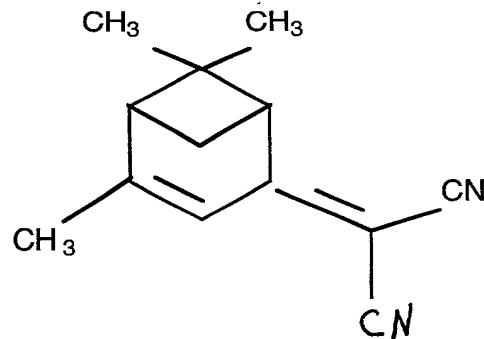
(I)



(II)



(III)



(IV)

4. A liquid-crystal dopant comprising a compound as claimed in Claim 1.

5. A liquid-crystal dopant comprising a compound as claimed in Claim 2.

6. A liquid-crystal dopant comprising a compound as claimed in Claim 3.

7. A liquid-crystal dopant having at about 20-30°C an absorption loss in the visible region of less than or equal to about 5%; having at about 20-30°C a dielectric anisotropy of greater than about 50; and having at about 20-30°C a viscosity lower than about 50 centi-poise.

8. A composition comprising a liquid-crystal mixture and a liquid-crystal dopant as claimed in Claim 7, wherein the composition at about 20-30°C has a  $\partial n/\partial T$  larger than about 0.005, wherein  $n$  is a refractive index of the composition at a visible wavelength and  $T$  is a temperature of the composition in °C.

9. A composition comprising a liquid-crystal mixture and a compound as claimed in Claim 1.

10. A composition as claimed in Claim 9, wherein the compound comprises less than or equal to about 50% by weight of the composition.

11. A method for reducing an operation voltage of a liquid-crystal mixture, the method comprising adding the compound claimed in Claim 1 to the liquid-crystal mixture.

12. A method as claimed in Claim 11, wherein an amount of the compound is added to and mixed with the liquid-crystal mixture to yield a resulting mixture, wherein the amount of the compound is less than or equal to about 50% by weight of the resulting mixture.

13. A method for tuning a clearing temperature of a liquid-crystal mixture, the method comprising adding the compound claimed in Claim 1 to the liquid-crystal mixture.

14. A method as claimed in Claim 13, wherein an amount of the compound is added to and mixed with the liquid-crystal mixture to yield a resulting mixture, wherein the amount of the compound is less than or equal to about 50% by weight of the resulting mixture.

15. A method for tuning birefringence of a liquid-crystal mixture, the method comprising adding the compound claimed in Claim 1 to the liquid-crystal mixture.

16. A method as claimed in Claim 15, wherein an amount of the compound is added to and mixed with the liquid-crystal mixture to yield a resulting mixture, wherein the amount of the compound is less than or equal to about 50% by weight of the resulting mixture.

17. A method for increasing a  $\partial n/\partial T$  of a liquid-crystal mixture, the method comprising adding the compound claimed in Claim 1 to the liquid-crystal mixture to yield a resulting mixture, wherein the resulting mixture at about 20-30°C has a  $\partial n/\partial T$  larger than about 0.005, wherein  $n$  is a refractive index of the resulting

mixture and T is a temperature of the resulting mixture in °C.

18. A method as claimed in Claim 17, wherein an amount of the compound is added to and mixed with the liquid-crystal mixture to yield the resulting mixture, wherein the amount of the compound is less than or equal to about 50% by weight of the resulting mixture.

19. A compound as claimed in Claim 1, wherein  
wherein when D is  $\text{NR}_a\text{R}_b$ , then  $\alpha$  is greater than or equal to 1 and less than or equal to 25;

wherein when  $\text{R}_1$ ,  $\text{R}_m$ ,  $\text{R}_n$ ,  $\text{R}_q$ , and  $\text{R}_r$  are each H, and  $\text{R}_o$ ,  $\text{R}_p$ , and D are each  $-\text{CH}_3$ , A is not  $\text{C}(\text{CN})(\text{CN})$ ;

wherein when  $\text{R}_1$ ,  $\text{R}_m$ ,  $\text{R}_n$ ,  $\text{R}_o$ , and  $\text{R}_p$  are each H, and  $\text{R}_q$ ,  $\text{R}_r$ , and D are each  $-\text{CH}_3$ , A is not  $\text{C}(\text{CN})(\text{CN})$ ;

wherein when  $\text{R}_1$ ,  $\text{R}_o$ ,  $\text{R}_p$ ,  $\text{R}_q$ , and  $\text{R}_r$  are each H, and  $\text{R}_n$ ,  $\text{R}_m$ , and D are each  $-\text{CH}_3$ , A is not  $\text{C}(\text{CN})(\text{CN})$ ; and

wherein when  $\text{R}_1$ ,  $\text{R}_m$ ,  $\text{R}_n$ ,  $\text{R}_o$ ,  $\text{R}_p$ ,  $\text{R}_q$ , and  $\text{R}_r$  are each H, and D is  $-\text{CH}_3$ , A is not  $\text{C}(\text{CN})(\text{CN})$ .

20. A composition as claimed in Claim 9, wherein the composition is a liquid-crystal composition.

## Abstract

High-dielectric colorless or virtually colorless dopants for low-voltage and tunable clearing temperature liquid-crystal devices. These dopant compounds help reduce the operation voltage for both polar and non-polar liquid-crystal (LC) mixtures. Methods for making and using these dopant compounds are also disclosed.

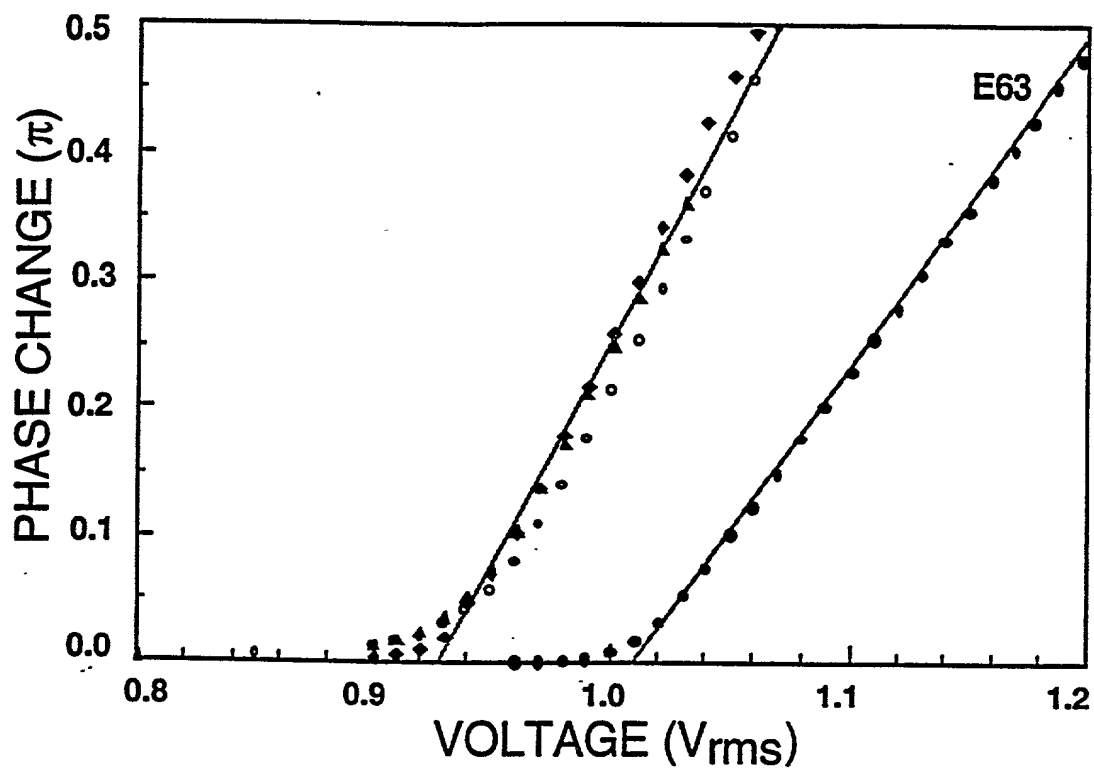


FIGURE 1

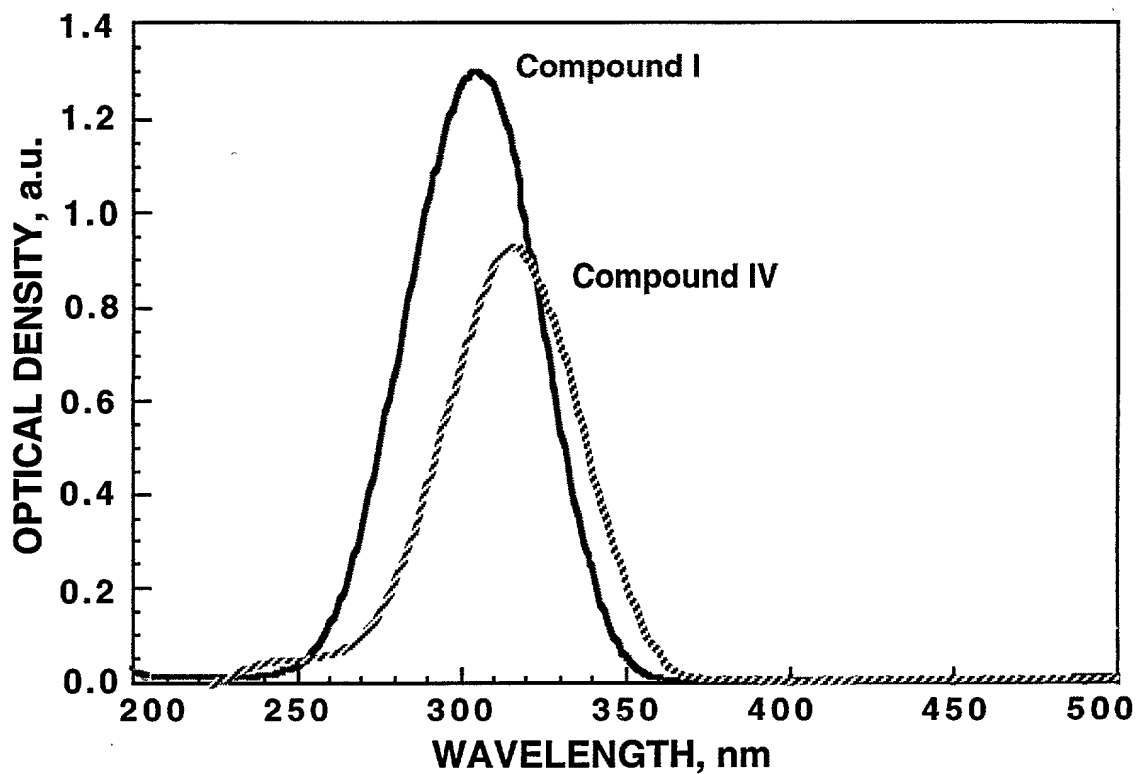


FIGURE 2



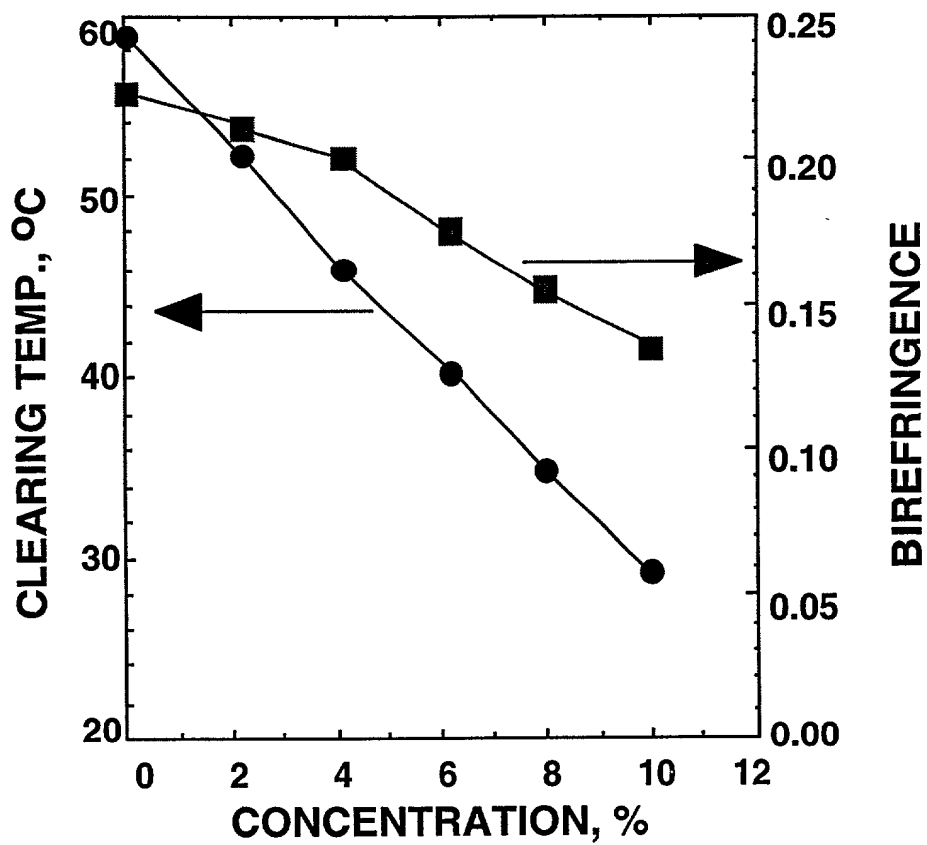


FIGURE 3

Attorney's Docket No. B-3539 616758-3**COMBINED DECLARATION AND POWER OF ATTORNEY***(ORIGINAL, DESIGN, NATIONAL STAGE OF PCT, SUPPLEMENTAL, DIVISIONAL, CONTINUATION, OR CIP)*

As a below named inventor, I hereby declare that:

**TYPE OF DECLARATION**This declaration is of the following type: *(check one applicable item below)*

- ☒ original  
☐ design  
☐ supplemental

**NOTE:** *If the declaration is for an International Application being filed as a divisional, continuation or continuation-in-part application, do not check next item; check appropriate one of last three items.*

- ☐ national stage of PCT

**NOTE:** *If one of the following 3 items apply, then complete and also attach ADDED PAGES FOR DIVISIONAL, CONTINUATION, OR CIP.*

- ☐ divisional  
☐ continuation  
☐ continuation-in-part (CIP)

**INVENTORSHIP IDENTIFICATION**

**WARNING:** *If the inventors are each not the inventors of all the claims an explanation of the facts, including the ownership of all the claims at the time the last claimed invention was made, should be submitted.*

My residence, post office address and citizenship are as stated below next to my name. I believe I am the original, first and sole inventor *(if only one name is listed below)* or an original, first and joint inventor *(if plural names are listed below)* of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**TITLE OF INVENTION**"DOPANTS FOR LIQUID-CRYSTAL DEVICES"**SPECIFICATION IDENTIFICATION**the specification of which: *(complete (a), (b) or (c))*

- (a) ☒ is attached hereto.  
 (b) ☐ was filed on \_\_\_\_\_ as ☐ Serial No. 0 / \_\_\_\_\_  
 or ☐ Express Mail No., as Serial No. not yet known, \_\_\_\_\_  
 and was amended on \_\_\_\_\_ *(if applicable)*.

**NOTE:** *Amendments filed after the original papers are deposited with the PTO which contain new matter are not accorded a filing date by being referred to in the declaration. Accordingly, the amendments involved are those filed with the application papers or, in the case of a supplemental declaration, are those amendments claiming matter not encompassed in the original statement of invention or claims. See 37 CFR 1.67.*

- (c) ☐ was described and claimed in PCT International Application No. \_\_\_\_\_  
 filed on \_\_\_\_\_ as amended under PCT Article 19 (1)  
 on \_\_\_\_\_ *(if any)*.

### ACKNOWLEDGMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code Federal Regulations § 1.56.

☐ In compliance with this duty there is attached an information disclosure statement 37 CFR 1.97.

### PRIORITY CLAIM

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign applications(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed.

(complete (d) or (e))

- (d) ☒ no such applications have been filed.  
(e) ☐ such applications have been filed as follows.

NOTE: Where item (c) is entered above and the International Application which designated the U.S. claimed priority check item (e), enter the details below and make the priority claim.

### EARLIEST FOREIGN APPLICATION(S), IF ANY, FILED WITHIN 12 MONTHS (6 MONTHS FOR DESIGN(S)) PRIOR TO THIS U.S. APPLICATION

COUNTRY	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 37 USC 119
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO
			<input type="checkbox"/> YES <input type="checkbox"/> NO

### ALL FOREIGN APPLICATION(S), IF ANY FILED MORE THAN 12 MONTHS (6 MONTHS FOR DESIGN(S)) PRIOR TO THIS U.S. APPLICATION

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## POWER OF ATTORNEY

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(List name and registration number)*

Richard P. Berg, Reg. No. 28,145  
William R. Evans, Reg. No. 25,858  
Mavis S. Gallenson, Reg. No. 32,464  
Peter D. Galloway, Reg. No. 27,885

Kam C. Louie, Reg. No. 33,008  
Richard J. Paciulan, Reg. No. 28,248  
John Palmer, Reg. No. 36,885  
William C. Boling, Reg. 41,625

*(check the following item, if applicable)*

☐ Attached as part of this declaration and power of attorney is the authorization of the above-named attorney(s) to accept and follow instructions from my representative(s).

### SEND CORRESPONDENCE TO:

John Palmer  
c/o LADAS & PARRY  
5670 Wilshire Boulevard, Suite 2100  
Los Angeles, California 90036-5679

### DIRECT TELEPHONE CALLS TO:

*(Name and telephone number)*

John Palmer

(323) 934-2300

## DECLARATION

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

## SIGNATURE(S)

Full name of **sole or first inventor** Shin-Tson WU

Inventor's signature \_\_\_\_\_

Date \_\_\_\_\_ Country of Citizenship U.S.A.

Residence Northridge, California

Post Office Address 19138 Frankfort Street, Northridge, California 91324

Full name of **second joint inventor**, if any Seth Marder

Inventor's signature \_\_\_\_\_

Date \_\_\_\_\_ Country of Citizenship U.S.A.

Residence Tuscon, Arizona

Post Office Address 3085 East Manzanita Ridge Place, Tuscon, Arizona 85718

Full name of **third joint inventor**, if any Qing T. Zhang

Inventor's signature \_\_\_\_\_

Date \_\_\_\_\_ Country of Citizenship China

Residence Tuscon, Arizona

Post Office Address 3401 North Columbus Boulevard, Apt. 13J, Tuscon, Arizona 85712

**CHECK PROPER BOX(ES) FOR ANY OF THE FOLLOWING ADDED PAGES(S)  
WHICH FORM A PART OF THIS DECLARATION**

- ☐ Signature for third and subsequent joint inventors. *Number of pages added* \_\_\_\_\_
- ☐ Signature by administrator(trix), executor(trix) or legal representative for deceased or incapacitated inventor. *Number of pages added* \_\_\_\_\_
- ☐ Signature for inventor who refuses to sign or cannot be reached by person authorized under 37 CFR 1.47. *Number of pages added* \_

\*\*\*

- ☐ Added pages to combined declaration and power of attorney for divisional, continuation-in-part (CIP) application.  
*Number of pages added* \_\_\_\_\_

\*\*\*

- ☐ Authorization of attorney(s) to accept and follow instructions from representative.

\*\*\*

***If no further pages form a part of this Declaration then end this Declaration with this page and check the following item.***

- ☒ This declaration ends with this page.

DECLARATION OF INVENTOR